

Volatility Spillovers, Comovements and Contagion in Securitized Real Estate Markets

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Abstract This paper analyzes the relationships between local and global securitized real estate markets, but also between securitized real estate and common stock markets. First, the volatility transmissions across markets are examined using an asymmetric t-BEKK (Baba-Engle-Kraft-Kroner) specification of their covariance matrix. Second, correlations from that model and tail dependences estimated using a time-varying copula framework are analyzed to assess whether different dynamics underlie the comovements in the whole distribution and those in the tails. Third, we investigate market contagion by testing for structural changes in the tail dependences. We use data for the U.S., the U.K. and Australia for the period 1990–2010 as a basis for our analyses. Spillover effects are found to be the largest in the U.S., both domestically and internationally. Further, comovements in tail distributions between markets appear to be quite important. We also document different dynamics between the conditional tail dependences and correlations. Finally, we find evidence of market contagion between the U.S. and the U.K. markets following the subprime crisis.

Keywords Volatility spillovers · Financial contagion · Asymmetric BEKK model · Copulas · Structural breaks · Real estate securities

JEL classification G11 · G15 · C32

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Introduction

Numerous studies have documented the benefits of including real estate in mixed-asset portfolios (Hoesli et al. 2004; MacKinnon and Al Zaman 2009). In practice, however, investing in real estate is not unproblematic given, for example, the high unit value and illiquidity of properties. Thus, it is not surprising that the importance of the securitized real estate market has grown substantially during the past decades, with the worldwide market capitalization reaching \$1,159 billion as of July 2010.¹ Indeed, the characteristics of real estate securities overcome many of the drawbacks related to direct real estate. Thus, an understanding of the nature of real estate stocks is crucial for investors seeking to invest in real estate by acquiring real estate stocks.

An important stream of research has developed in this area. Due to the hybrid nature of real estate stocks, many studies have examined the relationships with stocks, bonds and its underlying asset (i.e., real estate). Clayton and MacKinnon (2003), for instance, show that securitized real estate is mainly linked to the stock market. Other studies have documented that real estate securities have a strong relationship with the direct real estate market only in the case where a long-run analysis is realized (Geltner and Kluger 1998; Oikarinen et al. 2011). Some studies have focused on the factors underlying the return dynamics (Peterson and Hsieh 1997) and on those underlying the variance (Stevenson 2002). The interactions across national markets have also received much interest in the literature (see, for instance, Michayluk et al. 2006).

Using data for the U.S., the U.K. and Australia for the period 1990–2010, our paper analyzes the relationships between securitized real estate markets and common stock markets (national analysis), but also between local and global securitized real estate markets (international analysis). The first part of our investigation is motivated by the fact that real estate stocks are stocks by definition, even though the underlying asset is direct real estate. With the international analysis, we will be able to assess the scope of influence of each of these three national markets on the global market and vice versa. As those markets play an important role in the worldwide economy as well as in real estate markets, a better understanding of their characteristics is warranted.

The first objective of this paper is to study the volatility spillover dynamics by means of news impact surfaces (developed by Kroner and Ng 1998) plotted by using the parameter estimates from an asymmetric t-BEKK (Baba-Engle-Kraft-Kroner) specification of the covariance matrix. The second objective is to investigate the relationships by focusing only on the extreme events in the series. Both constant and time-varying tail dependences are calculated by means of the symmetrized Joe-Clayton copula (Patton 2006). The limits of using a linear approach to model the dependence between random variables (e.g. correlations) have been extensively documented in the literature.² Dependence measures based on copulas address this issue as they allow capturing the nonlinear dependence between random variables. In addition, the time-varying tail dependences are compared to conditional

¹ *European Public Real Estate Association (EPRA), Monthly Statistical Bulletin* of July 2010.

² See, for instance, Embrechts et al. (2002).

correlations computed from the BEKK model so that differences in their evolution through time can be assessed.

The third objective of this research is to assess the impact of a crisis (with a focus on the recent financial crisis) on the fundamental relations between markets. In other words, we test for financial contagion according to the definition of Forbes and Rigobon (2002), namely the presence of a significant increase of cross-market linkages after a shock. We combine the copula theory used in this study with a structural break test developed by Dias and Embrechts (2004) for testing for financial contagion. Utilizing tail dependences for expressing the cross-market linkages is in line with Bae et al. (2003) who stress the importance of extreme events for testing contagion: “The concerns about contagion are generally founded on the presumption that there is something different about extremely bad events that leads to irrational outcomes, excess volatility, and even panics. In the context of stock returns, this means that if panic grips investors as stock returns fall and leads them to ignore economic fundamentals, one would expect large negative returns to be contagious in a way that small negative returns are not.”³ This supports the idea that an analysis of the shifts in correlations as a manner of identifying the presence of any contagion is of limited scope.

Besides the fact that we do not work with correlations, our methodology has the further advantage that there is no discretion in defining what “usual” is as would be the case with the extreme value theory (EVT). In this respect, we overcome a drawback of an EVT-based approach. Another way to work in this spirit would be to assess the connections between markets after having controlled for economic fundamentals. However, contagion being associated to high frequency data, such type of data is not available for macroeconomic variables (Moser 2003). Our methodology does not require macroeconomic data. For those reasons, it is particularly appealing for testing financial contagion.

Since the U.S. market is recognized as having been the center of the recent financial crisis, this part of the analysis only considers those pairs which include the U.S. Thus, our study is carried out on the following pairs: U.S. and U.K. securitized real estate markets, U.S. and Australian securitized real estate markets, and finally U.S. equity and securitized real estate markets. The analysis of this latter pair is motivated by the intuition that the contagion may also occur across different sectors of a given country. This was the case e.g. during the Asian flu; the real estate market plummeted and then affected the rest of the financial sector (see Kallberg et al. 2002).

Our study yields a number of interesting results. First, for the national analyses, we find the strongest volatility spillovers and asymmetry in the U.S.; the other two countries exhibiting more mitigated relations and asymmetry. As regards the international analyses, it appears that the three local markets influence more the volatility of the global market than the reverse, providing evidence of the importance of those markets. Except to some extent for Australia, we find that those interactions are not driven by exchange rate factors. Second, the extreme joint behavior of the series analyzed shows rather high tail dependence coefficients in both the national and international analyses. In general, we also document an asymmetric feature underlying these extreme comovements. Those results are supported by the time-

³ Bae et al. (2003, p. 718–719).

varying tail dependences that exhibit quite high levels. We also find that the conditional tail dependences remain rather stable over our sample period for each pair studied. The conditional correlations do not follow the same evolution, especially since 2005. Finally, concerning financial contagion, we observe such a phenomenon only between the U.S. and the U.K. following the subprime crisis and not the recent financial crisis. The other pairs do not show similar results. However, two structural breaks are found in the relationships between U.S. stock and securitized real estate markets, but their time of occurrence does not correspond to any obvious crisis.

This paper contributes to the existing literature in three ways. First, we introduce a methodology for testing financial contagion which has never been used for this purpose. As mentioned above, this methodology has many advantages. We include in our analysis the recent global financial and real estate crises which have received very little attention from a financial contagion point of view. Second, no paper has covered as thoroughly the different aspects of the interactions between assets or markets (i.e., volatility spillovers, extreme joint behavior, and financial contagion). As a consequence, little has been said about the comparison of the results from the analysis of extreme returns and those from the analysis of the entire distribution. Finally, few studies have sought to investigate whether there are some mutual influences between the global securitized real estate market and a local market. Indeed, research to date has mainly focused on the relationships between two national markets. We contribute therefore to the debate on whether assets are globally priced.⁴

The paper is organized as follows. The next section contains a literature review, while the following section presents the data as well as some descriptive statistics. The two following sections explain the methods used in this study and the empirical results, respectively. A final section contains some concluding remarks.

Literature Review

The interactions between various assets or markets have been the subject of much attention in recent years. Indeed, for portfolio diversification purposes, this field of study has interested both academics and practitioners. The very first papers focused on stock market inter-linkages at an international level analyzing the return and volatility dynamics underlying the financial markets. Much attention has been given to the volatility spillovers. These studies include Hamao et al. (1990), Bae and Karolyi (1994), and Karolyi (1995).⁵ An ARCH (*Autoregressive Conditional Heteroscedasticity*) modeling framework for short-run analysis is used to characterize the volatility transmission. In most cases, there is significant evidence of interdependence. Moreover, Bae and Karolyi (1994) show for the U.S. and Japan that bad news affect more strongly the volatility transmission than good news.

⁴ See Ling and Naranjo (2002) for a study finding evidence of a worldwide factor driving securitized real estate returns.

⁵ For further studies on volatility spillovers involving the equity market, see Karolyi and Stulz (1996), King et al. (1994), and Susmel and Engle (1994).

Evidence of non constant correlations across time, another important characteristic of international market linkages, is shown by Longin and Solnik (1995). Baele (2005) shows increasing volatility spillover effects in the Western European markets. A similar conclusion is reached by Bekaert et al. (2009), using risk-based factor models, while these authors find mixed evidence of interdependence in other regions.

Given the benefits of being exposed to real estate in a portfolio context, but also the drawbacks of investing in direct real estate, real estate securities have been the focus of much research. Being stocks by definition, real estate stocks are obviously influenced by the broader stock market; such influences having been analyzed in several papers. Using multi-factor asset pricing techniques, Ling and Naranjo (1999) find that the real estate investment trust (REIT) market is integrated with that of stocks; however, no such evidence is found in relation to the direct real estate market. Studies such as Stevenson (2002) and Cotter and Stevenson (2006) also report strong relationships based on volatility transmission tests conducted with different GARCH models or time-varying correlations. In the first paper, several univariate GARCH models with exogenous variables are used. A particular link with the small cap and value stocks is found. This result is intuitively appealing as real estate stocks have similar characteristics to these assets. In the second paper, the authors conclude that the frequency of the data might have an influence on the empirical results. Using a symmetric BEKK⁶ model and daily returns, they find that the stocks of large firms impact more strongly the real estate security market than when monthly returns are used. A more recent paper by Yang et al. (2010) documents the strong asymmetric correlations between REITs and the S&P500 during the period 1998–2008 by means of a multivariate asymmetric generalized dynamic conditional correlation GARCH model. To some extent, we can thus conclude that the broader stock market impacts the real estate security market.

Investors increasingly seek to go international on real estate markets, spurring much research in this area. The aim of these studies is to assess whether a common international factor is at play in the various domestic real estate security markets. Michayluk et al. (2006) look at the asymmetric volatility transmission, the correlations and the return dynamics between the U.S. and U.K. securitized real estate markets. Using the ADC (*Asymmetric Dynamic Covariance*) model proposed by Kroner and Ng (1998), they find that the two markets are linked when synchronously priced data are examined and that there exists an asymmetric effect on both the volatilities and the correlations between the markets. Using a multivariate dynamic conditional correlation model (Engle 2002), Liow et al. (2009) study the international linkages between listed real estate markets (across countries and across regions). They detect higher correlations amongst the stock markets than amongst the securitized real estate markets. Furthermore, a strong and positive connection is found between the conditional correlations and their volatilities. Finally, the international real estate stock market correlations are linked to those of the broader stock market.

⁶ Miao et al. (2011), and Wong et al. (2007) also use the symmetric BEKK model for volatility spillover purposes, but analyze the housing markets, and the real estate spot and forward markets, respectively.

Liow and Newell (2011), using an asymmetric BEKK model, report evidence of volatility transmissions within Greater China and between Greater China and the U.S. By means of regression techniques, they also evaluate the impact of the recent financial turmoil on the correlations and find a significant increase. Using eight Asian markets, Liow (2012) analyzes the dynamics underlying the international correlations between stocks and securitized real estate at a local, regional and global level by means of an asymmetric dynamic conditional correlation model (Cappiello et al. 2006). Liow also looks at changes in correlation and covariance's composition (volatilities and correlations) following the recent financial crisis. He finds some time-varying and asymmetric links as well as the importance played by the crisis. Taking into account the possibility to have regime-dependent returns (using Bai and Perron's 2003 methodology) and volatilities (using a multivariate regime-dependent asymmetric dynamic covariance methodology), Liow et al. (2011) detect mean and volatility interdependences (across different regimes) in five major securitized real estate markets. Going beyond a GARCH framework, Yunus (2009), basing her analysis on cointegration tests, and Zhou (2010), adopting a wavelet analysis, also study the comovements across international markets. The former author documents increasing common behavior, whereas the latter does not find such a pattern.

The analysis of extreme events appearing in financial series is a stream of research becoming increasingly popular. For instance, Longin and Solnik (2001) estimate the extreme correlations of international equity markets using the EVT and find that the correlations increase in bear markets. Again employing the EVT, Liow (2008) calculates the value-at-risk of property stocks and concludes that these assets present important features of extreme risks. However, much emphasis has been placed on analyzing such events using a methodology based on copulas. For instance, Jondeau and Rockinger (2006) use copulas to model international stock markets. Patton (2006) pioneered the inclusion of time-variation in copulas by developing conditional asymmetric tail dependences. He applies this extension of the theory of copulas to the Forex market and finds evidence of asymmetric tail dependence. As regards the real estate field, Knight et al. (2005) choose the constant symmetrized Joe-Clayton copula for examining the relationships between real estate and stocks for both the U.K. and global markets. Generally, strong tail dependence is shown by the authors, particularly in the negative tail. Employing the same copula, but allowing the parameters of the copula to be time-varying (Patton 2006), Gao and Zhou (2010) study the conditional tail dependences of six major global markets (U.S., U.K., Japan, Australia, Hong Kong and Singapore). They conclude that the levels of the tail dependences vary amongst the different pairs created. Within the same methodological framework, Goorah (2007) discusses the limitations of the linear correlations by estimating tail dependences between the U.S. and the U.K. property stock markets. Finally, Simon and Ng (2009) examine the impact of the real estate/mortgage crisis on the linkages between REITs and equities. Based on the results coming from a flexible mixed-copula approach, they observe that REITs have an important ability to protect against numerous downturns of the U.S. stock market.

The impact of a crisis on financial markets is of paramount interest for both investors and policymakers. This area of research has also been widely documented by researchers. However, the paper by Forbes and Rigobon (2002) represents the cornerstone of research in this area because they question the reality of contagion by

giving a more precise definition of this term: for observing contagion, we must find a significant increase of cross-market linkages after a shock to one country. The first papers that empirically implement such a definition base their measure of cross-market linkages on correlations via time series models; for instance, Caporale et al. (2005) and Chiang et al. (2007). Both sets of authors find evidence of contagion in the Asian markets after the crisis of 1997. Another possibility to test for financial contagion involves the use of extreme situations. The idea was brought forward by Bae et al. (2003), who estimate the “coincidence of extreme return shocks across countries”. Using a multinomial logistic regression model, they detect contagion phenomena in the emerging markets during the 1990s. In line with this paper, Rodriguez (2007), using data from the markets influenced by the Asian crisis or the Mexican crisis, investigates the structural breaks in the tail dependences modeling the inter-linkages between the markets by implementing a switching-parameter copulas. Only the Asian markets experience an increase in their tail dependence. Financial contagion in Asia is also found by Bekaert et al. (2005). To do so, the authors develop a two-factor asset pricing model and look at the correlations in the residuals after controlling for the local and foreign shocks.

Real estate markets have also been the subject of financial contagion analyses. Kallberg et al. (2002) examine the regime shifts in the structural relations between the equity and real estate security markets in eight developing Far Eastern countries. The methodology of Bai et al. (1998) is used in this paper. They find regime shifts appearing quite synchronously across the countries analyzed (i.e., evidence of contagion) during the Asian crisis. They also document that real estate did not cause the crisis. By means of a multivariate cointegrated system allowing for structural breaks (endogenously determined), Gerlach et al. (2006) also study the impact of the Asian crisis on the links between real estate security markets in the Asian-Pacific region. Their results reveal a structural break during the crisis. The transmission of the Asian crisis across national real estate markets is also examined by Bond et al. (2006). Using a multivariate latent factor framework, reduced diversification opportunities after the crash are found by the authors.

Data and Preliminary Statistics

The real estate security data are sourced from the EPRA/NAREIT⁷ database and the stock market data from *Thomson Reuters Datastream*. We use weekly closing prices of national and global indices covering the period December 28, 1989 to May 28, 2010, thus yielding approximately 1,100 observations. If a market was closed one trading day because of a holiday, the price observation of that day has been replaced by that of the previous trading day. Three national markets have been chosen, i.e., those of the U.S., the U.K. and Australia.

Working with international indices raises the issue of discrepancies in the opening hours of stock exchanges around the world. Indeed, a study by Martens and Poon (2001) shows that daily stock market correlations are affected by the use of non-synchronous data. Moreover, as the trading volume of real estate stocks is much

⁷ European Public Real Estate Association/National Association of Real Estate Investment Trusts.

smaller than that of other assets, one might expect longer delays in the reactions to foreign news (Michayluk et al. 2006). This is because lack of liquidity in a market leads to less and slower information flows across markets. We circumvent these issues by using weekly data; this also addresses the potential problem related to a day-of-the-week effect.

The global indices are expressed in the currency of the country under analysis. Thus, we take the perspective of an investor who is not hedged against currency risk. In order to avoid biases in the empirical results, the domestic market studied is excluded from the world index. However, such an index is not available for Australia in the EPRA/NAREIT database. Given the limited size of the Australian securitized real estate market (\$69 billion as of July 2010 representing about 6% of the world market), this should not have a noticeable influence on the results. Logarithmic returns are calculated from the different indices for the analyses in this paper.

Table 1 provides descriptive statistics for real estate stock returns in the three countries analyzed. The four moments are reported first. Given that we use weekly data, the mean return is close to zero, while the standard deviations are comprised between 2.50% and 3.10%. U.S. real estate stocks are the riskiest and offer the highest returns as well. All the return series are leptokurtic and negatively skewed, inconsistent with a normal distribution. In addition, the Jarque-Bera statistics reject the null hypothesis of normality at the 1% significance level.

An augmented Dickey-Fuller (ADF) test with trend and four lags was performed in order to check for stationarity. The unit-root null hypothesis is rejected (the series are stationary) and thus the returns do not need to be transformed before the models' estimations. The raw and the squared returns are characterized by the presence of strong autocorrelations (Ljung-Box Q test). The conditional heteroskedasticity is also, more formally, confirmed by the Lagrange multiplier test of Engle (1982)

Table 1 Summary statistics—real estate stocks

Statistics			
	United States	United King.	Australia
Mean	0.225	0.057	0.165
Std Deviation	3.024	2.960	2.514
Skewness	−0.472	−0.899	−2.076
Kurtosis	16.467	9.612	22.420
Jarque-Bera	8,088.024 ^b	2,083.421 ^b	17,500.653 ^b
ADF unit-root	−13.492 ^b	−12.751 ^b	−14.475 ^b
Q(12)	26.017 ^a	26.509 ^b	147.132 ^b
Q ² (12)	1,355.217 ^b	865.809 ^b	575.559 ^b
ARCH(1) LM test	359.909 ^b	113.969 ^b	7.940 ^b

This table presents descriptive statistics at the weekly frequency for real estate stocks for the period December 28, 1989 to May 28, 2010. The mean and standard deviation are expressed in percentage.

^a denotes significance at the 5% level, ^b denotes significance at the 1% level

Table 2 Correlations

	U.S.	U.K.	Australia
Panel A: Real Estate Stocks—Stocks			
Coefficients	0.612	0.619	0.626
Panel B: Real Estate Stocks—Global Real Estate Stocks			
Coefficients	0.459	0.510	0.398

This table presents the correlation coefficients between real estate stocks and stocks (Panel A) and real estate stocks and global real estate stocks (Panel B)

which detects the presence of ARCH effects. Similar results prevail with the other data. In short, the statistical distribution characteristics of our series support the usage of ARCH models.

As a first step in the analysis of the interdependences between the markets, linear correlations are evaluated. Table 2 indicates high correlations between stocks and securitized real estate (figures of about 0.60). Lower levels are found in the international context, with correlation coefficients of about 0.50 for the U.S. and U.K., whereas the coefficient does not exceed 0.40 for Australia.

Methods

Multivariate GARCH Model

Our first aim is to investigate the volatility transmission dynamics between different markets; therefore a multivariate GARCH setup is appropriate.⁸ The Baba-Engle-Kraft-Kroner (BEKK) specification of the variance-covariance matrix defined in Engle and Kroner (1995), which is a restrictive version of the original VEC model (Bollerslev et al. 1988), has been chosen. This specification has two main advantages. First, it reduces considerably the number of parameters to be estimated especially when the dimensions of the model are large. Second, it ensures the positive definiteness of the variance-covariance matrix due to the last three terms of the equation which are expressed in quadratic forms (see Eq. 2), provided that the constant term is positive definite.

According to the model proposed by Glosten et al. (1993) in a univariate framework, a leverage term is added to the original BEKK expression of the conditional covariance matrix. Thus, we obtain an asymmetric t-BEKK specification of the variance-covariance matrix. Each variable in the model is considered with a lag of one and the mean equation is modeled as a vector autoregressive process of order one. For ease of interpretation purposes, a series of bivariate models are estimated. Indeed, larger dimensions would lead to some difficulties in isolating the

⁸ The univariate version of the ARCH and GARCH models were first established by Engle (1982) and Bollerslev (1986), respectively.

various effects. Thus, the asymmetric t-BEKK model is characterized by the following equation:

$$R_t = K + DR_{t-1} + \varepsilon_t \quad (1)$$

where $R_t = \begin{bmatrix} r_{1t} \\ r_{2t} \end{bmatrix}$, $K = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix}$, $D = \begin{bmatrix} d_{11} & d_{21} \\ d_{12} & d_{22} \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$ and where $\varepsilon_t = \Sigma_t^{1/2} z_t$, with $z_t \sim i.i.d. \text{ Student-}t(\nu)$, thus $\varepsilon_t | \Phi_{t-1} \sim \text{Student-}t(0, \Sigma_t, \nu)$ with:

$$\Sigma_t = CC' + A'\varepsilon_{t-1}\varepsilon_{t-1}'A + B'\Sigma_{t-1}B + N'\Psi_{t-1}\Psi_{t-1}'N \quad (2)$$

where $C = \begin{bmatrix} c_{11} & 0 \\ c_{12} & c_{22} \end{bmatrix}$, $A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$, $B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$, $N = \begin{bmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{bmatrix}$, where A , B and N are 2×2 parameter matrices and C is a lower triangular matrix of constant terms (2×2). The error term is represented by ε_t . Equations (1) and (2) represent the mean equation and the asymmetric t-BEKK specification of the time-varying covariance matrix, respectively. The asymmetry term is expressed by the last part in Eq. 2 where $\Psi_t = \min(0, \varepsilon_t)$.

Due to the quadratic form of the asymmetric t-BEKK parameterization, the volatility spillovers are impossible to trace properly. To overcome this issue, we do not comment the parameter estimates and instead use news impact surfaces (three-dimensional graph), a methodology proposed by Kroner and Ng (1998). Holding information at time $t-1$ constant by setting Σ at its unconditional mean value and treating the innovations as a collection of news arriving to a market (Engle and Ng 1993), the news impact surfaces (NIS) for the conditional second moments are expressed by means of the following function (over the range $\varepsilon_{i,t} \in [-4, 4]$):

$$\sigma_{ij,t} = \sigma_{ij}(\varepsilon_{i,t-1}, \varepsilon_{j,t-1}; \Phi_{t-1} = \Phi). \quad (3)$$

Under the assumption that the residuals ε_t follow a bivariate Student's t distribution with mean zero, covariance matrix Σ_t conditional to the information available until $t-1$ (Φ_{t-1}) and degrees of freedom ν ($2 < \nu < \infty$), we perform a quasi-maximum likelihood estimation.⁹ The aim of this estimation is to find values for the parameters θ which maximize the following log-likelihood function:

$$L(\theta) = \sum_{t=1}^T \ln \left[\frac{\Gamma(1 + \nu/2)}{\pi(\nu - 2)\Gamma(\nu/2)} \left(1 + \frac{\varepsilon_t' \Sigma_t^{-1} \varepsilon_t}{\nu - 2} \right)^{-(\nu+2)/2} \right] - \sum_{t=1}^T \frac{\ln(|\Sigma_t|)}{2} \quad (4)$$

where $\Gamma(\cdot)$ is the gamma function and T is the length of the time series observed. The real joint distribution of the innovations does not necessarily follow a bivariate Student's t distribution, thus this methodology can be referred to as quasi-maximum. However, in order to obtain consistent results it is crucial to use the approach of Bollerslev and Wooldridge (1992) to compute robust standard errors and thus to correct the initial misspecification of the density function.

⁹ The Student's t distribution partially captures the leptokurtosis of the innovations. Besides, the BEKK model coupled with a bivariate Student's t distribution represents one of the most flexible multivariate models available (Ang and Bekaert 2002).

Copulas

Evaluating the dependence between extreme events is a useful tool for risk management purposes. An obvious candidate for such an analysis is the copula framework. Simply speaking, copulas are “functions that join or couple multivariate distribution functions to their one-dimensional marginal distribution functions” (Nelsen 2006).

Copula Definition

Consider two random variables (X, Y) with respective marginal distribution functions $F_x(x)$ and $F_y(y)$ and their joint distribution $F_{xy}(x, y)$. Sklar (1959) states that there exists a function C called copula which joins the marginal distributions:

$$F_{xy}(x, y) = C(F_x(x), F_y(y)). \quad (5)$$

Then, if we set $u = F_x(x)$, $v = F_y(y)$ with $0 \leq u \leq 1$, $0 \leq v \leq 1$ where both are uniformly distributed, we obtain a function $C(u, v)$ defined on a unit rectangle. C covers all possible bivariate distribution functions. In sum, a copula describes the dependence structure existing between two random variables. The estimation procedure requires two stages (called Inference Function for Margins; for further details, see Joe and Xu 1996) and a semi-parametric approach is used. First, the marginal distributions for the univariate variables are constructed and estimated nonparametrically. Second, the parameters of the copula are estimated by a parametric approach.

Marginal Distributions

In keeping with the financial literature and the discussion contained in the previous section, first we filter the return series by an AR(1)-GJR-t-GARCH(1,1):

$$r_t = c + \beta r_{t-1} + \varepsilon_t \quad (6)$$

$$\varepsilon_t = \sqrt{\sigma_t^2} z_t, \text{ with } z_t \sim i.i.d. \text{ Student} - t(v)$$

$$\varepsilon_t | \Phi_{t-1} \sim \text{Student} - t(0, \sigma_t^2, v)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \phi I_{\varepsilon_{t-1} < 0} \varepsilon_{t-1}^2 \quad (7)$$

where $I_{\varepsilon_{t-1} < 0}$ is a binary variable which takes the value of one if the error term is negative, zero otherwise. Second, we estimate the marginal distributions from the residuals obtained in the first step nonparametrically by an empirical cumulative distribution function:

$$\hat{F}_j(x_j) = \frac{1}{T} \sum_{t=1}^T I_{x'_j < x_j} \quad (8)$$

where $I_{x'_j < x_j}$ is the indicator function which takes the value of one if the argument is true, zero otherwise.

Copula Function and Tail Dependence

In order to model asymmetric tail dependence, the symmetrized Joe-Clayton (SJC) copula proposed by Patton (2006) has been employed which is a modification of the Joe-Clayton (JC) copula of Joe (1997). This latter is expressed as follows:

$$C_{JC}(u, v | \tau^U, \tau^L) = 1 - \left(1 - \{ [1 - (1 - u)^\kappa]^{-\gamma} + [1 - (1 - v)^\kappa]^{-\gamma} - 1 \}^{-1/\gamma} \right)^{1/\kappa} \quad (9)$$

where $\kappa = 1/\log_2(2 - \tau^U)$, $\gamma = -1/\log_2(\tau^L)$ and $\tau^U \in (0, 1)$, $\tau^L \in (0, 1)$. τ^L and τ^U are the two parameters of the JC copula and represent the lower and upper tail dependences, respectively. The first measure of dependence is defined as:

$$\tau^L = \lim_{q \rightarrow 0} P(U \leq q | V \leq q) = \lim_{q \rightarrow 0} P(V \leq q | U \leq q) = \lim_{q \rightarrow 0} \frac{C(q, q)}{q} \quad (10)$$

where $U = F_x(x)$ and $V = F_y(y)$. There is a lower tail dependence if the previous limit exists and $\tau^L \in (0, 1]$. $\tau^L = 0$ indicates lower tail independence. Similarly, the upper tail dependence is defined as:

$$\tau^U = \lim_{\delta \rightarrow 1} P(U > \delta | V > \delta) = \lim_{\delta \rightarrow 1} P(V > \delta | U > \delta) = \lim_{\delta \rightarrow 1} \frac{1 - 2\delta + C(\delta, \delta)}{1 - \delta}. \quad (11)$$

There is an upper tail dependence if the previous limit exists and $\tau^U \in (0, 1]$. $\tau^U = 0$ indicates upper tail independence. Finally, we will have tail symmetry (asymmetry) if $\tau^L = \tau^U$ ($\tau^L \neq \tau^U$).

The SJC copula is characterized by the following formula:

$$C_{SJC}(u, v | \tau^U, \tau^L) = 0.5 \cdot (C_{JC}(u, v | \tau^U, \tau^L) + C_{JC}(1 - u, 1 - v | \tau^U, \tau^L) + u + v - 1). \quad (12)$$

In a reduced form, we obtain the following general expression:

$$\hat{F}(x, y | \tau^U, \tau^L) = C_{SJC}(\hat{F}_x(x), \hat{F}_y(y); \tau^U, \tau^L). \quad (13)$$

The copula parameters τ^L and τ^U of Eq. 13 are estimated by the maximum likelihood method. The sum of the logarithm of the density function of the copula is maximized given the estimated parameters for the marginal models.

In the previous models, the tail dependences were constant across time (constant SJC copula). However, it is quite unrealistic to assume that these measures of dependence are constant. In order to capture their evolution, a time-varying copula is used in a second analysis. Patton (2006) established a time-varying SJC copula where the evolution across time of τ^L and τ^U is expressed by the following two equations:

$$\tau_t^L = \Lambda \left(\omega_L + \beta_L \tau_{t-1}^L + \alpha_L \cdot \frac{1}{10} \sum_{j=1}^{10} |u_{t-j} - v_{t-j}| \right) \quad (14)$$

$$\tau_t^U = \Lambda \left(\omega_U + \beta_U \tau_{t-1}^U + \alpha_U \cdot \frac{1}{10} \sum_{j=1}^{10} |u_{t-j} - v_{t-j}| \right) \quad (15)$$

where $\Lambda(x) \equiv (1 + e^{-x})^{-1}$ is the logistic transformation. This transformation constraints the tail dependences to stay in $(0, 1)$ during all the period.¹⁰

Thus, two analyses of the extreme return relationships are performed in this paper; one with constant tail dependences and another one with time-varying tail dependences.

Structural Break Test in Copula Models

The methodology presented in this section is utilized in order to test for financial contagion across markets. Our aim is to analyze whether or not we find structural breaks in the dependence structure between two markets around financial stressful times. Obviously, other important events might affect the dependence structure. The copula approach presented in the previous section is used for modeling the dependence. This is in accordance with the idea by Bae et al. (2003) who pointed out to the importance of extreme situations for assessing the contagion phenomenon. Thus, we go further than the conventional approach based on structural shifts in correlations.

The structural break test developed by Dias and Embrechts (2004) for detecting the presence of a breakpoint in the dependence parameter of a static copula is used in this paper. This test appears appropriate for two main reasons. First, it involves the use of copulas which are of interest in our research because of their accuracy in modeling the dependence structure. Second, the time of occurrence of a structural break is not chosen exogenously but given directly by the method. For contagion test purposes, this point is paramount as it has been shown by Dungey and Zhumabekova (2001) that the size of crisis and non-crisis periods can affect significantly the contagion conclusions.

Suppose U_1, U_2, \dots, U_T are a sequence of independent random vectors in $[0, 1]^d$ with univariate uniformly distributed margins and copulas $C(u; \theta_1, \eta_1), C(u; \theta_2, \eta_2), \dots, C(u; \theta_T, \eta_T)$; θ_i are the parameters of the copula function, whereas η_i are the parameters of the margins treated as nuisance parameters and set as constant. The null hypothesis of no structural break in the copula parameters is as follows:

$$H_0 : \theta_1 = \theta_2 = \dots = \theta_T \text{ and } \eta_1 = \eta_2 = \dots = \eta_T,$$

whereas the alternative hypothesis of presence of a structural break is:

$$H_1 : \theta_1 = \dots = \theta_{k^*} \neq \theta_{k^*+1} = \dots = \theta_T \text{ and } \eta_1 = \eta_2 = \dots = \eta_T.$$

If the null hypothesis is rejected, k^* is the time of the single change-point. If the breakpoint is known, the test statistic is based on a generalized likelihood ratio test.¹¹ The idea behind this test is to verify if a population can be better explained by separating the total sample in two parts. The following equation corresponds to the likelihood ratio statistic:

$$LR_k = 2 \left(L_K(\hat{\theta}_k, \hat{\eta}_k) + L_k^*(\theta_k^*, \hat{\eta}_k) - L_T(\hat{\theta}_T, \hat{\eta}_T) \right) \quad (16)$$

¹⁰ For further details on the development of this methodology, see Patton (2006).

¹¹ For further details, see Dias and Embrechts (2004) and Csörgő and Horváth (1997).

where $L_k(\hat{\theta}_k, \hat{\eta}_k)$, $L_k^*(\theta_k^*, \hat{\eta}_k)$ and $L_T(\hat{\theta}_T, \hat{\eta}_T)$ correspond to the log-likelihood functions of the copula in Eq. 13 before the break, after the break and for the full sample, respectively. In a more realistic case where the breakpoint date is unknown, a recursive procedure is used and the test statistic becomes:

$$Z_T = \max_{1 \leq k < T} LR_k. \quad (17)$$

The null hypothesis will be rejected for large values of this statistic. The critical values are computed according to the approximation for the distribution of $Z_T^{1/2}$ proposed by Csörgő and Horváth (1997) and also used by Dias and Embrechts (2004).

Then, for estimating the time of the breakpoint, the maximum likelihood estimator of this time is given by:

$$\hat{k}_T = \min\{1 \leq k < T : Z_T = LR_k\}. \quad (18)$$

This estimator will take a value near the boundaries of the sample if we cannot conclude to the presence of a change-point. In the case where we suppose that several changes in the copula parameters might exist, we adopt a sequential procedure proposed by Vostrikova (1981), also used in Dias and Embrechts (2004). This method consists in a segmentation procedure of our sample every time we find a significant break. If the null hypothesis is rejected for the full sample, the breakpoint is used as a boundary for constructing two subsamples (one before the change and one after the change), where we apply again our likelihood ratio test to each of them. The segmentation procedure continues until we do not find a significant breakpoint in any of the sets.

In order to evaluate the contagion phenomenon, we re-estimate the lower and upper tail dependences from the static SJC copula for each subsample constituted by the structural break test presented above and analyze the changes in the parameter values. At least one parameter must significantly change for there to be a break. For having financial contagion, we must observe an increase of the lower tail dependence after a shock.

Empirical Results

This section is divided into four parts. First, the volatility spillovers are discussed on the basis of the news impact surfaces for both types of analysis (i.e. domestic and international). Second, the results from the static copula analysis of the tail dependences are commented. The third part is devoted to the dynamic aspects of the previous investigations. In this subsection, we also compare the time-varying correlations to the tail dependences. Finally, the outcomes of our financial contagion analysis are discussed.

Table 3 Asymmetric BEKK results—local analysis

Parameters	Coefficients (Robust t-stats)					
	U.S.		U.K.		Australia	
a_{11}	-0.290 ^b	(-4.17)	0.171 ^b	(2.58)	0.245 ^b	(5.83)
a_{12}	-0.179 ^b	(-5.93)	0.033	(0.30)	0.029	(0.26)
a_{21}	0.098 ^b	(2.89)	-0.030	(-0.07)	0.012	(0.58)
a_{22}	0.219 ^b	(6.69)	-0.079	(-1.17)	0.036	(0.13)
b_{11}	0.950 ^b	(48.29)	0.967 ^b	(49.83)	0.965 ^b	(16.34)
b_{12}	-0.002	(-0.23)	0.013	(0.75)	0.039	(0.63)
b_{21}	-0.029 ^a	(-2.14)	-0.031	(-0.80)	-0.011	(-0.10)
b_{22}	0.938 ^b	(50.53)	0.932 ^b	(22.84)	0.924 ^b	(10.47)
n_{11}	0.279 ^b	(5.08)	0.237	(1.45)	-0.038	(-0.11)
n_{12}	0.045	(1.29)	-0.002	(-0.02)	-0.240	(-1.91)
n_{21}	0.056	(0.95)	0.131 ^a	(1.99)	0.053	(0.22)
n_{22}	0.313 ^b	(3.79)	0.394 ^b	(3.56)	0.440 ^a	(1.96)
DoF	7.365 ^b	(6.46)	9.141 ^b	(4.13)	9.058 ^b	(5.51)
Log-likelihood	5,516.41		5,351.05		5,793.91	
Diagnostic tests						
$Q_1^2(6)$		1.13		8.420		6.935
$Q_2^2(6)$		3.76		2.371		2.970

In this table, the first column shows the coefficient estimates from the asymmetric t-BEKK model for the national analysis, while the robust t-statistics are reported in parentheses. ^a denotes significance at the 5% level, ^b denotes significance at the 1% level

Volatility Spillovers

Domestic Analysis

The parameter estimates of the bivariate asymmetric t-BEKK model for the domestic analysis are reported in Table 3. Several parameters are statistically significant for each country; the results for the U.K. and Australia exhibiting, however, less significance than those for the U.S. Those parameters are not utilized for interpreting the volatility transmission dynamics, however, due to the difficulties to trace those dynamics because of the quadratic form of the model. The model captures some leptokurtosis through the degree of freedom parameter (highly significant) of the Student's *t*-distribution and fits well the data based on the Ljung-Box Q-test performed on the squared standardized residuals (no autocorrelation left). To gauge the importance of the asymmetric part added to the model, we also conduct a likelihood ratio test (LRT)¹² on the three series and conclude that this addition increases the explanatory power of the model.

¹² The results of this test are not reported. They can be obtained upon request.

Figure 1 displays the NIS for the U.S. (on the top, for the variance of securitized real estate and stocks; at the bottom, for the covariance and the correlation). The securitized real estate variance is larger when its own lagged innovations are negative, supporting the idea of asymmetry. The variance is even larger when its own negative innovations are combined with positive shocks coming from the stock market, meaning that the securitized real estate market is the most volatile when it declines while the equity market performs well. The spillover effect from the stock market to the real estate market is quite apparent given that the real estate variance changes for varying levels of news coming from the equity market (for a given level of real estate news). However, this is the case only when the real estate innovations are large. Some asymmetry appears in the spillovers, especially when we have positive shocks stemming from the real estate market. Relatively similar patterns are found for the equity variance dynamics; however, with a more pronounced asymmetry.

The conditional covariance reaches its highest level when the shocks from the two markets are of opposite sign, whereas the correlation is particularly strong at each extreme situation except in the case where the news are extremely positive for both markets. The correlation behavior reinforces the idea of asymmetry in the inter-linkages between the two assets. In sum, stocks and real estate securities are strongly linked and they influence each other's volatility.

The NIS related to the U.K. market are reported in Fig. 2. In comparison to the U.S. case, quite different conclusions emerge. Indeed, the securitized real estate variance is slightly influenced by the news from the common stock market, but only so when the innovations in the real estate market are extremely negative. In contrast, the securitized real estate market has almost no impact on the equity variance. Furthermore, the asymmetric behavior of the variance appears only according to the

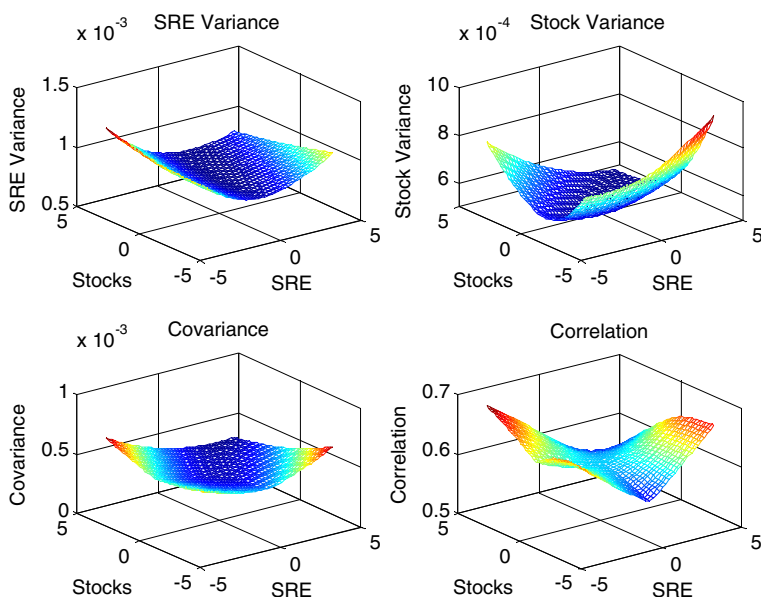


Fig. 1 News impact surfaces for the U.S.—local analysis

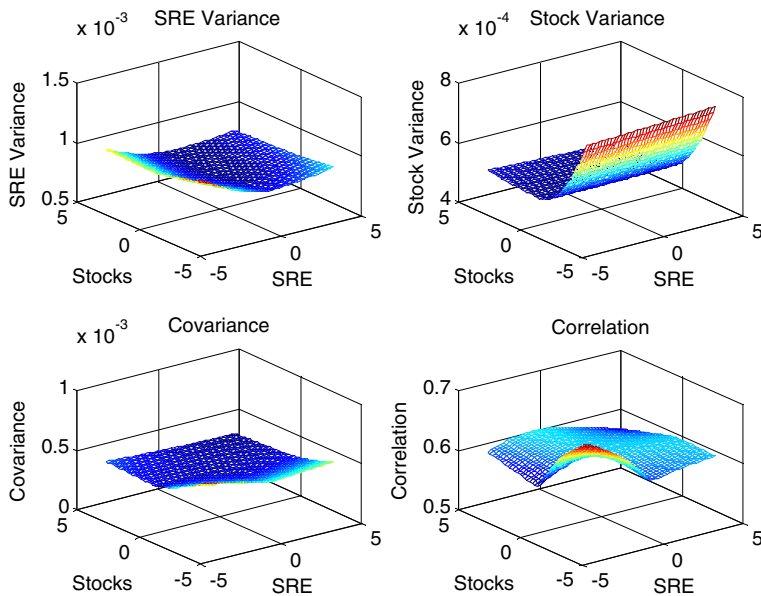


Fig. 2 News impact surfaces for the U.K.—local analysis

lagged innovations, the spillover effect remaining stable. The NIS of the covariance and the correlation are quite flat except when both assets produce negative shocks leading to an increase of the covariance and the correlation.

Figure 3 shows that the Australian real estate stock variance is not very sensitive to news arriving from the broader stock market, forming an U-shape. Thus, we can observe a strong symmetry characterizing the variance reaction to its own shocks. On the other hand, the stock variance is positively influenced by positive real estate news when its own innovations are negative, while otherwise it exhibits a rather stable variance without noticeable asymmetric behavior. The covariance NIS is bowl-shaped and the correlation is the highest with both positive and negative extreme shocks (saddle shape) confirming the previous observation of symmetry.

In summary, the results for the U.S. suggest tighter linkages across the two assets than is the case in the U.K. and Australia. In general, one would expect a strong asymmetry driving the conditional real estate stock variance because real estate companies generally employ high leverage levels. Indeed, given the underlying assets of those companies (i.e., real estate), lenders are willing to provide loans covering a large fraction of the assets' values. This asymmetry should be particularly strong in the U.S. given that real estate companies are more leveraged than those in the other two countries (Serrano and Hoesli 2010). Our results confirm these hypotheses.

International Analysis

In this section, we introduce an international dimension in our study by evaluating the relationships between the world securitized real estate market and the domestic securitized real estate market in each of the three countries. At this stage, we take the point of view of a local investor who is unhedged against the exchange rate risk.

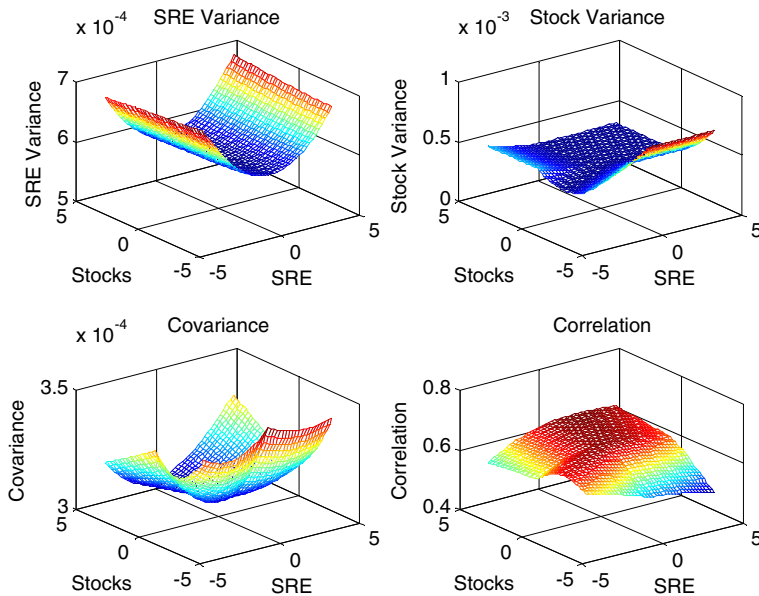


Fig. 3 News impact surfaces for Australia—local analysis

Table 4 exhibits the results of the specific bivariate GARCH utilized in this paper. The number of significant parameters is about the same across countries. Again, the fat tail feature of the data has been captured by the shape parameter of the Student's t -distribution and the LRT rejects the null hypothesis of no improvement of the model by adding the asymmetric part to the GARCH model. No autocorrelation is found after the model's estimation.

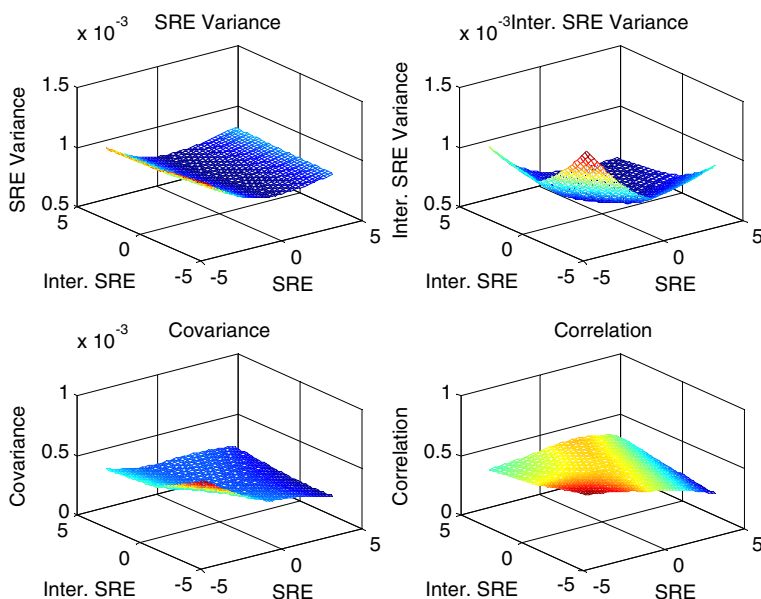
The news coming from the world market have little impact on the domestic markets studied (Figs. 4, 5 and 6; top left of the figures). The U.K. and Australian variances are weakly related to the world market news, whereas the U.S. variance is not. In all three countries, past innovations contribute to current variances. We also observe that the countries' variances influence the global variance. This result may a priori seem counter-intuitive. However, since we are studying important countries in terms of economic might and real estate security market capitalization, it is not all that surprising to find the U.S., U.K. and Australian markets influencing the variance of a global index (top right of the figures) rather than the reverse. The asymmetry is present in the spillover effects, but less so for Australia, showing that the interactions are tighter when markets decline globally. Each series also exhibits an asymmetric behavior according to its respective own lagged innovations. The covariance and correlation patterns are in line with volatility spillover and asymmetry findings, with higher levels when both series have extreme negative shocks (bottom of the figures referenced).

The U.S. being the world's largest economy, its influence on the world securitized real estate market is quite understandable. One possible explanation for the U.K. and Australian results might be the presence of regional or continental factors (Eichholtz et al. 1998) and the importance of those two economies in their respective region. Such regional factors could stem, for instance, from the fact that those countries have

Table 4 Asymmetric BEKK results—international analysis

Parameters	Coefficients (Robust t-stats)					
	U.S.		U.K.		Australia	
a ₁₁	0.212 ^a	(2.19)	−0.058	(−0.97)	0.152	(1.70)
a ₁₂	−0.192	(−1.54)	0.071	(1.38)	−0.084	(−0.87)
a ₂₁	0.020	(0.19)	0.049	(0.82)	0.060	(0.65)
a ₂₂	0.130	(0.80)	0.164 ^b	(2.96)	0.214 ^a	(2.28)
b ₁₁	0.960 ^b	(28.28)	0.990 ^b	(49.74)	0.957 ^b	(52.90)
b ₁₂	0.085	(1.71)	0.048 ^b	(2.69)	−0.002	(−0.06)
b ₂₁	−0.049	(−0.57)	−0.082	(−1.55)	0.005	(0.17)
b ₂₂	0.705 ^b	(4.47)	0.892 ^b	(27.78)	0.947 ^b	(26.55)
n ₁₁	0.290 ^b	(3.53)	−0.271 ^b	(−5.90)	0.237 ^b	(2.81)
n ₁₂	0.365 ^b	(2.99)	−0.028	(−0.50)	0.166	(1.13)
n ₂₁	0.050	(0.75)	−0.152	(−1.71)	−0.073	(−0.61)
n ₂₂	0.299 ^b	(3.78)	−0.268 ^b	(−4.35)	0.115	(0.38)
DoF	7.399 ^b	(6.89)	10.247 ^b	(5.41)	7.240 ^b	(6.59)
Log-likelihood	5,142.62		5,190.02		5,380.60	
Diagnostic tests						
Q ₁ ² (6)	2.101		6.485		4.403	
Q ₂ ² (6)	4.748		4.363		2.555	

In this table, the first column shows the coefficient estimates from the asymmetric t-BEKK model for the international analysis, while the robust t-statistics are reported in parentheses. ^a denotes significance at the 5% level, ^b denotes significance at the 1% level

**Fig. 4** News impact surfaces for the U.S.—international analysis

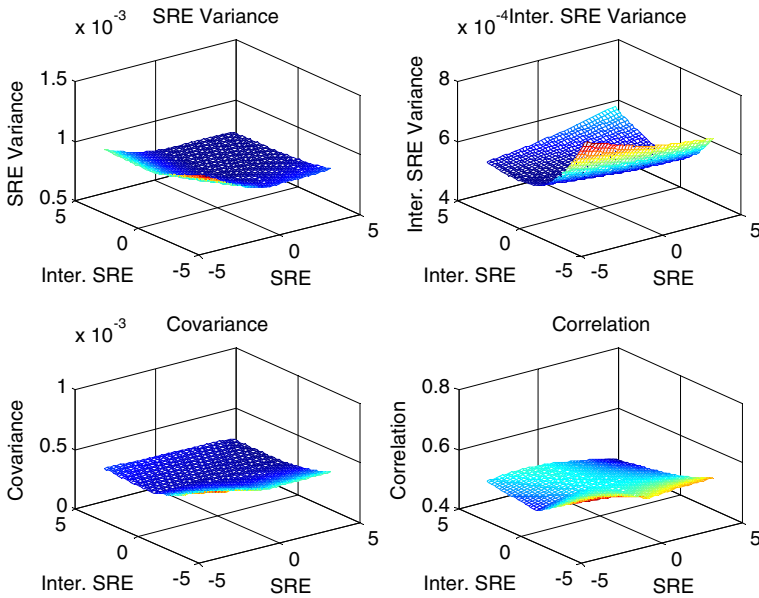


Fig. 5 News impact surfaces for the U.K.—international analysis

many trade agreements with countries in their area. By their influence on those regions in which other important markets also exist (for instance, France or Germany for Europe and Japan and Singapore for Asia), indirect repercussions may appear on the world index volatility. The hypothesis of regional factors influencing the securitized real estate markets might also be supported by the characteristics of such

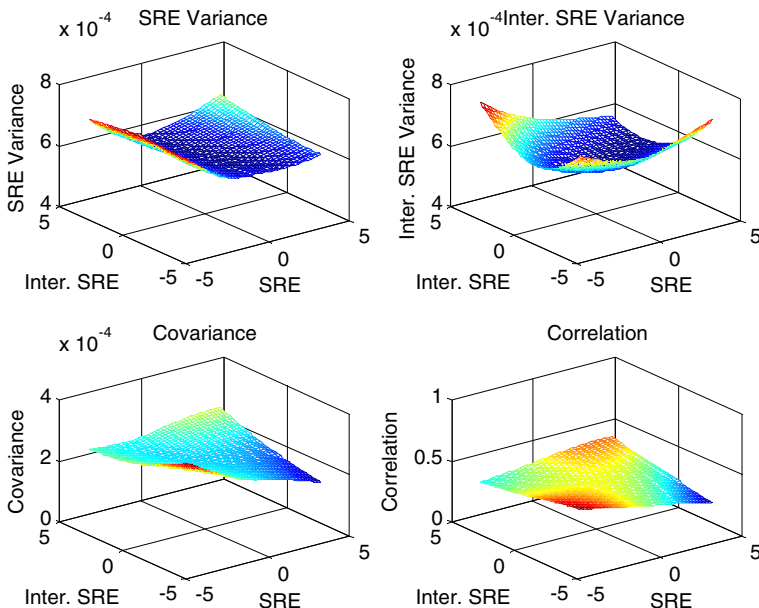


Fig. 6 News impact surfaces for Australia—international analysis

an asset. Indeed, due to the fact that real estate stocks behave to some extent as small capitalization stocks (Stevenson 2002), they should be more correlated to local, national, and regional economic activities (Bardhan et al. 2008).

Those findings concerning continental factors may also suggest stronger links of securitized real estate markets with direct real estate markets due to the importance of the “home” bias. Indeed, it is well known that people invest more in direct real estate in the region of their home country because some knowledge of the local economy is crucial, leading to national or regional factors influencing the real estate market. Thus, investors purchasing international real estate securities may behave in a similar fashion because they consider that this asset has similar risks or characteristics as its underlying asset.

The increasing tendency to introduce REIT-type structures across the world also contributes to reinforcing the international inter-linkages. Indeed, the tax-transparency inherent to a REIT system leads to increased transparency of the companies as a whole allowing potential and current investors to obtain more complete information about the financial prospects for such companies. Thus, the possibilities to invest abroad are more practicable and the information flows easier.

Robustness Checks

This section is devoted to the analysis of the sensitivity of the relationships found in the previous section to the exchange rate dynamics. So, the volatility transmissions are studied from the perspective of an investor who is hedged against currency risk. This goal is reached by expressing the global securitized real estate index in local currency (each domestic market included in the global index is denominated in its own currency). Although some differences emerge, the U.S. and U.K. interactions with the world market are not dissimilar. The changes for Australia are more pronounced in the volatility spillover patterns as well as in the asymmetry. The main change is that the news arriving from Australia do not have any impact on the world market anymore. Thus, the inter-linkages found in the previous section concerning that country appear to be driven largely by exchange rate factors.

Constant Tail Dependences

The purpose of this section is to evaluate the inter-linkages between markets during extreme conditions. To do so, both lower and upper tail dependence coefficients are estimated from the SJC copula (Table 5). Panel A contains the results of the domestic analysis. Overall, the levels of the tail dependences are quite important in the three markets, with parameters ranging from 0.25 to 0.50. According to the standard errors of these estimates, we reject in each case significantly the tail independence hypothesis. Another striking feature are the generally higher coefficients observed in the lower tail dependences in comparison with those in the upper tail dependences. A Wald test is performed to analyze the tail symmetry hypothesis. We find that an asymmetric feature characterizes the tail dependence dynamics in each market. Thus, the equity market is much more connected to the real estate stock market when both markets are crashing than when they are booming. These findings provide further evidence on the opportunity of diversifying

Table 5 Tail dependences—constant SJC copula

	U.S.	U.K.	Australia
Panel A: Real Estate Stocks—Stocks			
Lower	0.471 ^b (0.002)	0.476 ^b (0.002)	0.470 ^b (0.001)
Upper	0.270 ^b (0.001)	0.274 ^b (0.001)	0.345 ^b (0.000)
Wald test	Asymmetric	Asymmetric	Asymmetric
Panel B: Real Estate Stocks—Global Real Estate Stocks (Unhedged)			
Lower	0.255 ^b (0.002)	0.364 ^b (0.003)	0.188 ^b (0.002)
Upper	0.072 ^b (0.001)	0.102 ^b (0.001)	0.208 ^b (0.002)
Wald test	Asymmetric	Asymmetric	Symmetric

This table reports the estimated tail dependence coefficients (both lower and upper tail dependences) from the constant Symmetrized Joe-Clayton copula for the period 1990–2010. The standard errors are reported in parentheses. Panel A shows the results for the pair: securitized real estate and stocks and panel B for the pair: local securitized real estate and global securitized real estate. The Wald test results for tail symmetry are also reported. ^a denotes significance at the 5% level, ^b denotes significance at the 1% level

a mixed-asset portfolio as we obtain information on the joint behavior of these assets in the tail distribution, which cannot be achieved by a simple linear correlation measure.

Panel B shows the tail dependence results at the international level (with an unhedged strategy). All coefficients are statistically significant. The strongest lower tail dependence is registered for the U.K. (0.36), then the U.S. (0.26), with Australia exhibiting the lowest value (0.19). The upper tail dependences are usually weaker than the lower ones, except in Australia. The Wald test results validate the tail asymmetry for the U.S. and the U.K. and conclude to tail symmetry in Australia.

Consistent with our volatility spillover findings, our robustness checks¹³ point out to the importance of the exchange rate only on the results between Australia and the world market. The lower tail dependence increases notably, but without affecting the Wald test results (the tail symmetry remains). The results for the other two countries remain unchanged.

Time-varying Tail Dependences and Correlations

This section introduces a dynamic feature in the dependence measures. For comparison purposes, we also calculate conditional correlations from the asymmetric t-BEKK model. As Longin and Solnik (1995) show that the correlations are not constant through time, we can assume that a different picture (in comparison to a static analysis) should also emerge from the dynamic tail dependences. We will be able to evaluate the differences in the dynamics over our sample period between the conditional correlations and tail dependences. Thus, this part should contribute to the debate on the limits of using the correlation measure as relevant information for portfolio decision-making by disentangling the patterns underlying its evolution.

¹³ The results are not reported in this paper. They can be obtained upon request.

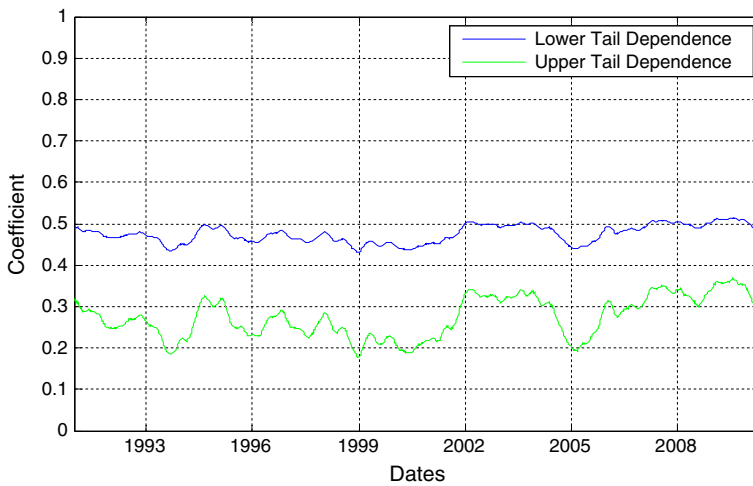


Fig. 7 Time-varying tail dependences/rolling-window for the U.S.—local analysis

The plotted conditional tail dependences and correlations that are presented in this section are smoothed tail dependences and correlations calculated using a 50-observation rolling-window process (Figs. 7, 8, 9, 10, 11, 12, 13 and 14). Such smoothing is needed to extract clear trends. The lower and upper tail dependences are plotted on the same graph for each pair, whereas the graphs for the correlations contain, for each specific analysis, the correlations for the three markets under investigation.

The time-varying lower and upper tail dependences for the local analysis are contained in Figs. 7, 8 and 9. The patterns across countries are quite similar with relatively constant linkages between equities and real estate securities from the beginning of the sample period until 2005–2006 (coefficients of about 0.40–0.50 for the lower tail dependences and of 0.30 for the upper tail dependences). Naturally, some spikes are registered occasionally during this period, but the coefficients return to a stable level not long thereafter. Another feature is the upward trend from 2005–

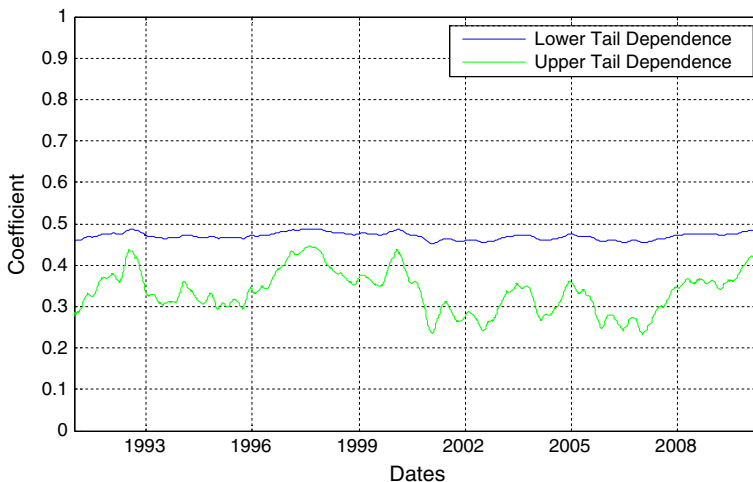


Fig. 8 Time-varying tail dependences/rolling-window for the U.K.—local analysis

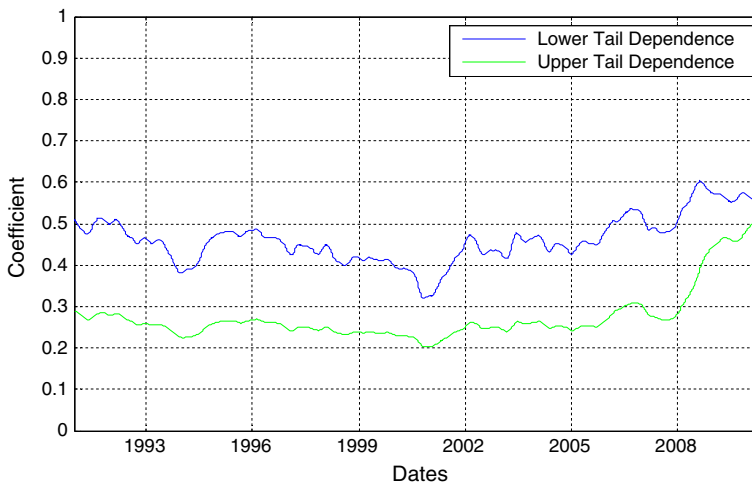


Fig. 9 Time-varying tail dependences/rolling-window for Australia—local analysis

2006 observed in Australia; the Australian securitized real estate market has an increasing tendency to behave like the broader stock market during extreme conditions since 2005. This upward trend is also visible in the U.S. and U.K., but less importantly so and only for the upper tail dependence. In all three countries, a clear asymmetry characterizes the conditional tail dependences.

For the first 15 years of our sample period, the evolution pattern of the conditional correlations across countries (Fig. 10) is consistent with that of tail dependences, namely a constant trend with coefficients in the 0.50–0.60 range. However, the period 2006–2010 shows different features in terms of dynamic behavior. Indeed, a strong positive trend emerges in all three countries when conditional correlations are used.

Focusing now on the results of the international analysis, we generally find less consistency across countries (Figs. 11, 12 and 13). The asymmetry is particularly marked in the U.K. and to a lesser extent in the U.S., whereas results suggest no clear asymmetry in Australia (similar conclusions were reached with the constant SJC copula). We find coefficients of about 0.25 and 0.10 in the U.S. and 0.35 and 0.10 in the U.K. on average for the lower and upper tail dependences, respectively. For Australia, coefficients of about 0.20 on average (for both tail dependences) are observed. Finally, except some peaks, constant tendencies over the 1990–2010 period are observed in all three countries.

As is the case with the local analyses, the dynamics of the conditional correlations (Fig. 14) diverge from those of the conditional tail dependences in the latter years of our sample period. Again, we observe a sharp increase in the correlations from 2007. Globally, these findings are not driven by exchange rate factors underlying the joint behavior of the series as we find robust results if we carry out the study with a currency risk hedging strategy.¹⁴

In general, a well diversified portfolio in usual times does not necessarily imply that it will be satisfactory diversified in stressful times; consequently consideration

¹⁴ The results are not reported in this paper. They can be obtained upon request.

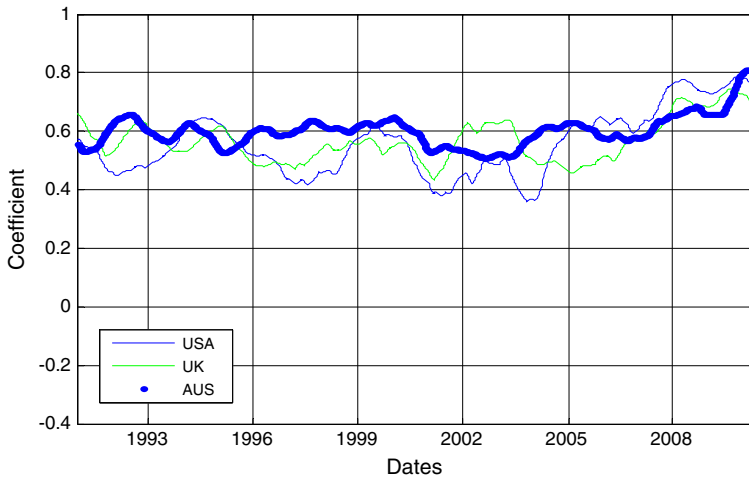


Fig. 10 Time-varying correlations/rolling-window—local analysis

of the extreme joint behavior of financial series is crucial. This is particularly true given that the biggest losses occur during extreme situations. Therefore, the financial implications of our findings, supportive of the idea that different dynamics underlie the evolution patterns of the correlations and of the tail dependences, are important.

Financial Contagion

This section is devoted to the study of financial contagion in securitized real estate markets. We combine two methodologies for testing for contagion, namely copulas and a structural break test. More specifically, we investigate the presence of structural breaks in the tail dependences without exogenously defining the time of occurrence of a shock. Thus, we adopt the definition of Forbes and Rigobon (2002) and the intuition of Bae et al. (2003) who assess “the coincidence of extreme return shocks across countries” when examining the evidence of contagion.

The pairs of series utilized are not the same as those used in the previous sections. Indeed, as our main aim is to test for the presence of financial contagion after the recent financial crisis, we focus only on the pairs including the U.S. market. This country has been identified as being the source of the global financial crisis as a consequence of the prior subprime crisis. Hence, we carry out our study of financial contagion for three pairs: The U.S. and U.K. securitized real estate markets; the U.S. and Australian securitized real estate markets; and finally the U.S. equity and securitized real estate markets.¹⁵ Table 6 reports the results of the structural break test¹⁶ of Dias and Embrechts (2004) as well as the dates of the structural breaks found.

¹⁵ The indices are expressed in local currency in order to avoid any impact of exchange rate factors on the analysis of financial contagion.

¹⁶ As we filtered our returns with an AR(1)-GJR-t-GARCH(1,1) model, we can assume that we have independent bivariate vectors with no structural break in the margins; therefore the conditions for applying the test of Dias and Embrechts (2004) are satisfied.

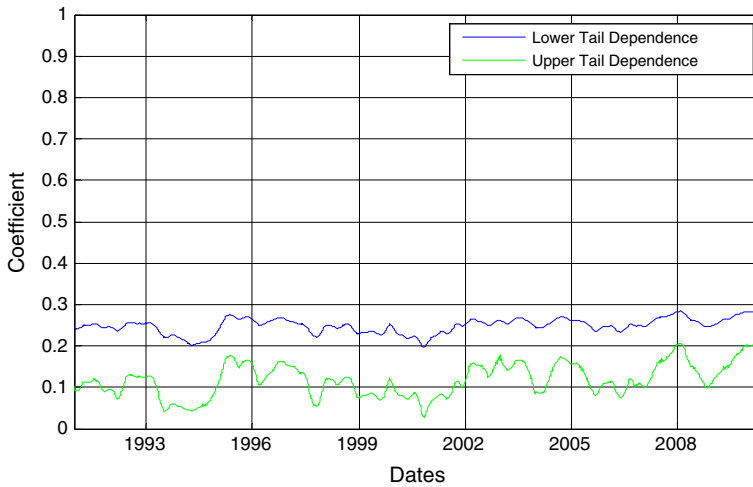


Fig. 11 Time-varying tail dependences/rolling-window for the U.S.—international analysis

From the three pairs under analysis, only the pair U.S.-Australia does not experience any structural break over our sample period meaning that their inter-linkages as expressed by their tail dependences have not significantly changed during the past 20 years (Table 6, Panel B). Consequently, we do not find any evidence of the crisis spreading from the U.S. to Australia during the recent financial turmoil. Indeed, with a test statistic of 3.06, there is not sufficient evidence to reject the null hypothesis of no change in the copula parameter(s). The estimates of the constant SJC copula (Table 7, Panel B) exhibit low levels of tail dependences (0.11 and 0.08 for the lower and upper tail dependences, respectively), which suggests very weak links between these two markets. A straightforward explanation is the presence of regional factors driving the real estate returns as already found in the volatility spillover analysis above and also shown by Eichholtz et al. (1998),

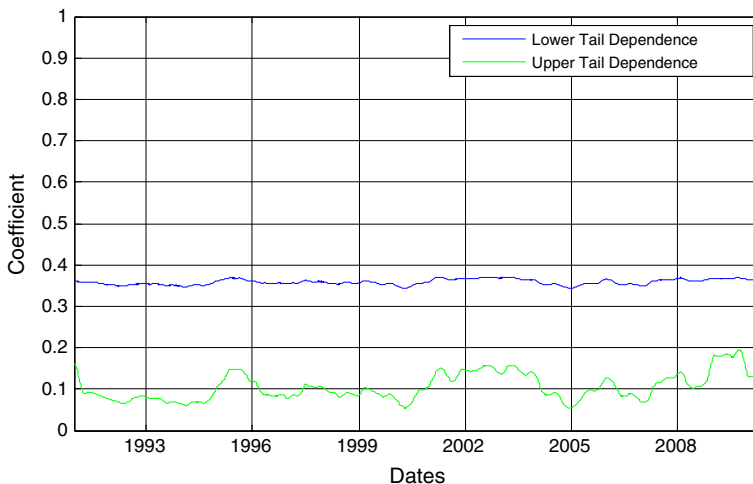


Fig. 12 Time-varying tail dependences/rolling-window for the U.K.—international analysis

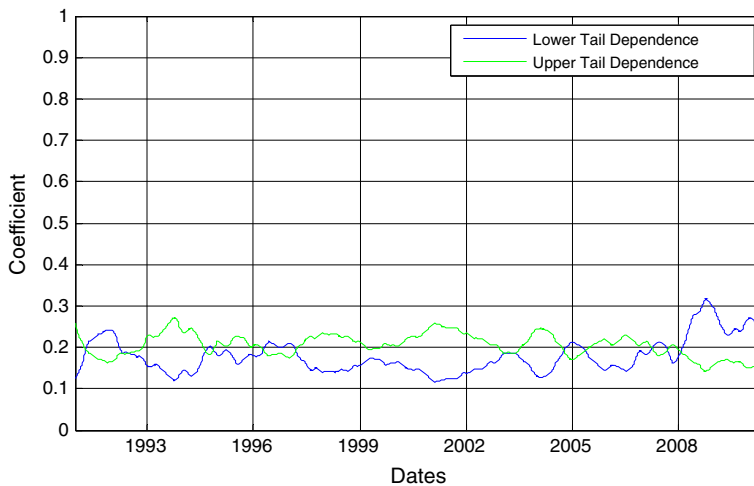


Fig. 13 Time-varying tail dependences/rolling-window for Australia—international analysis

complicating the propagation of shocks beyond the limits of a region. Finally, the Wald test for tail symmetry cannot be rejected.

The structural break test suggests a significant change in the copula parameter(s) modeling the extreme joint behavior of the U.S. and U.K. real estate stock markets. The test statistic takes the value of 4.30 and the null hypothesis is rejected with a p-value of 0.01 (Table 6, Panel A). The estimated time of the change occurred on January 26, 2007. The segmentation procedure used for testing multiple changes does not show other significant breaks in the two subsamples resulting from the first step. From Table 7 (Panel A), we observe a sharp increase of the lower and upper tail dependences which reach 0.55 and 0.31, respectively, after the break. Hence, we can conclude that the fundamental relations between the U.S. and U.K. markets changed and became tighter since 2007. This date corresponds to the beginning of the

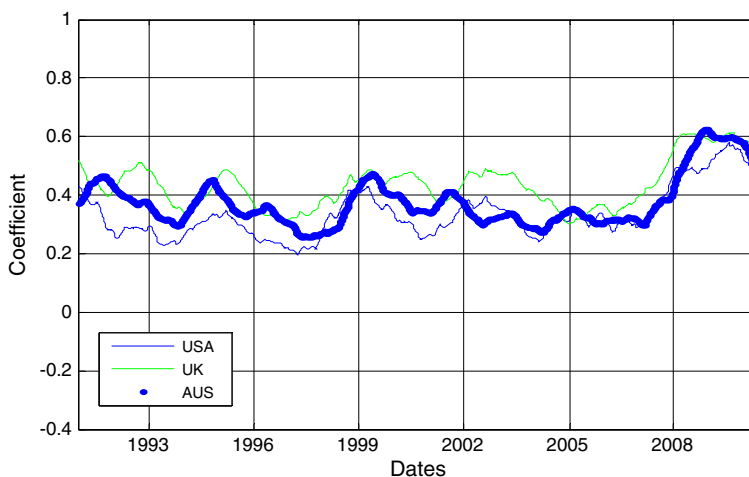


Fig. 14 Time-varying correlations/rolling-window—international analysis

Table 6 Tests for structural breaks in tail dependences

	Test Statistic	Sample Size	P-Value	$H_0(0.95)$	Time of change
Panel A: U.S. & U.K. Real Estate Stocks					
I	4.300	1064	0.007	Rejected	01/26/2007
II	3.365	889	0.133	Not Rejected	09/21/1990
	3.500	175	0.063	Not Rejected	04/13/2007
Panel B: U.S. & Australian Real Estate Stocks					
I	3.056	1064	0.297	Not Rejected	–
Panel C: U.S. Real Estate Stocks & Stocks					
I	5.551	1064	0.000	Rejected	12/03/2004
II	3.888	778	0.027	Rejected	01/05/1996
	3.222	286	0.152	Not Rejected	05/08/2009
III	2.964	314	0.282	Not Rejected	04/20/1990
	2.777	464	0.451	Not Rejected	01/23/1998

This table reports the test statistics, the p-values and the time of change from the structural break test of Dias and Embrechts (2004). Panel A shows the results for the pair U.S. and U.K. real estate stock markets; Panel B shows the results for the pair U.S. and Australian real estate stock markets; and panel C shows the results for the pair U.S. stock and real estate stock markets

subprime crisis leading to the conclusion that this shock spread from the U.S. to the U.K. The sharp increase in the lower tail dependence is consistent with the definition of financial contagion.

We note that the contagion appeared before the recent financial crisis in the U.S., implying that the catalyst of the financial contagion in the securitized real estate

Table 7 Tail dependences with structural breaks

	Lower	Upper	Wald test
Panel A: U.S. & U.K. Real Estate Stocks			
1990–2007	0.190 ^b (0.000)	0.007 ^b (0.000)	Asymmetric
2007–2010	0.550 ^b (0.015)	0.313 ^b (0.003)	Symmetric
Panel B: U.S. & Australian Real Estate Stocks			
1990–2010	0.112 ^b (0.002)	0.084 ^b (0.002)	Symmetric
Panel C: U.S. Real Estate Stocks & Stocks			
1990–1996	0.495 ^b (0.002)	0.327 ^b (0.001)	Asymmetric
1996–2005	0.382 ^b (0.005)	0.157 ^b (0.004)	Symmetric
2005–2010	0.617 ^b (0.003)	0.547 ^b (0.002)	Symmetric

This table reports the estimated tail dependence coefficients (both lower and upper tail dependences) from the constant Symmetrized Joe-Clayton copula for the subsamples resulting from the structural break test of Dias and Embrechts (2004); see Table 6. The standard errors are reported in parentheses. Panel A shows the results for the pair U.S. and U.K. real estate stock markets; Panel B shows the results for the pair U.S. and Australian real estate stock markets; and panel C shows the results for the pair U.S. stock and real estate stock markets. The Wald test results for tail symmetry are also reported. ^a denotes significance at the 5% level, ^b denotes significance at the 1% level

market was not the recent financial crisis, but rather the subprime crisis. As we do not find any subsequent structural break, we can assume that the new relationship patterns have been driven essentially by the subprime crisis. The past has shown in several instances the tight economic and political relations between the U.S. and the U.K., which constitute favorable conditions for such a shock transmission. International agreements constitute an important channel of shock transmission as those increase the information flows between partners as discussed in Longstaff (2010)¹⁷ and shown empirically by Forbes (2002). Kallberg et al. (2002) also suggest that firm leverage may be an additional factor for explaining structural breaks. Those two reasons can potentially explain the contagion phenomenon existing between the U.S. and the U.K. markets.

Finally, we find two significant structural breaks in the tail dependence(s) between the equity and real estate stock markets in the U.S. (Table 6, Panel C). The corresponding dates are January 05, 1996 and December 03, 2004 and their respective test statistics take the values of 3.88 (p-value of 0.03) and of 5.55 (p-value of 0). The remaining of the subsamples stemming from the segmentation procedure do not show any other significant break. The estimates of the constant SJC copula parameters for the three subsamples highlight the strong relationships between these two assets. The weakest tail dependences are registered in the intermediate period (1996–2005), while the highest values occur during the period 2005–2010. The most important increase pertains to that of the upper tail dependence between the second and the third subsample.¹⁸ As regards the Wald test, it rejects the null hypothesis of tail symmetry only for the period 1990–1996. To summarize, the extreme links dropped in 1996 and rose again in 2005 reaching coefficients of about 0.62 and 0.55 (lower and upper tail dependences, respectively) and behave in an increasingly symmetric fashion.

The structural breaks found between stocks and securitized real estate are not the sign of a financial contagion phenomenon as no particular crisis corresponds to the time of the changes. Nevertheless, other important economic phenomena may explain these changes in the fundamental relationships. The first break in the 1990s coincides with the growth of U.S. securitized real estate markets which led to a much more complete informational content weakening the relations between stocks and REITs (Khoo et al. 1993). The second change might be due to the real estate bubble in the U.S. preceding the subprime crisis. This hypothesis is supported by the fact that the largest changes are reported in the upper tail dependence for this structural break (real estate prices were especially high during the period preceding the subprime crisis).

For a more visual analysis, we also decided to estimate the time-varying tail dependences resulting from Eqs. (14) and (15) with the various structural breaks found in the static case. These measures are plotted in Figs. 15, 16 and 17. The results are consistent with those reported with the constant SJC copula (Table 7).

¹⁷ Longstaff (2010) reviews two other mechanisms of shock transmission: Contagion through the liquidity channel and contagion through the time-varying risk premiums. These mechanisms are not discussed in this paper as they do not constitute the purpose of our study.

¹⁸ The significant change could have occurred only to the upper tail dependence as we test for a change in one parameter only or in both parameters.

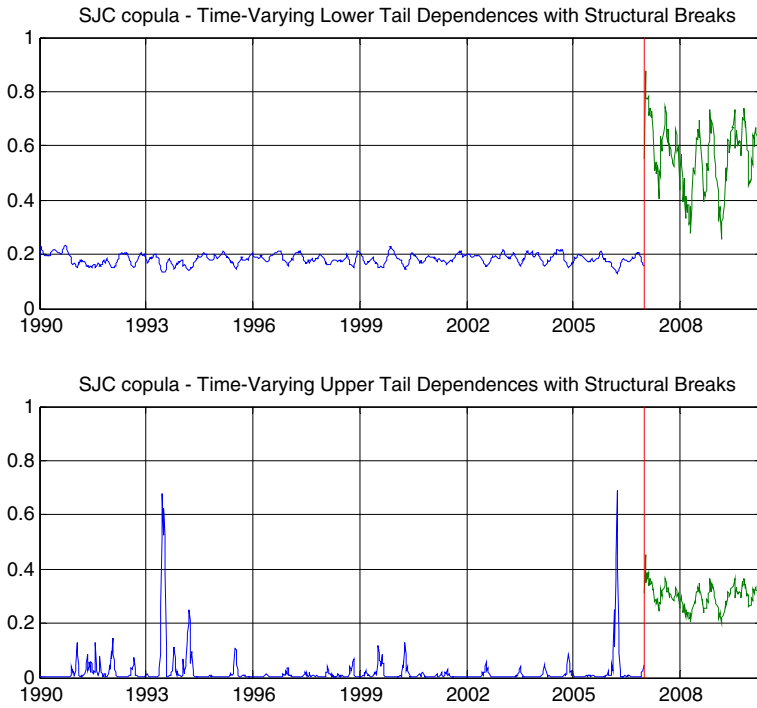


Fig. 15 Time-varying tail dependences with structural breaks—U.S. & U.K.

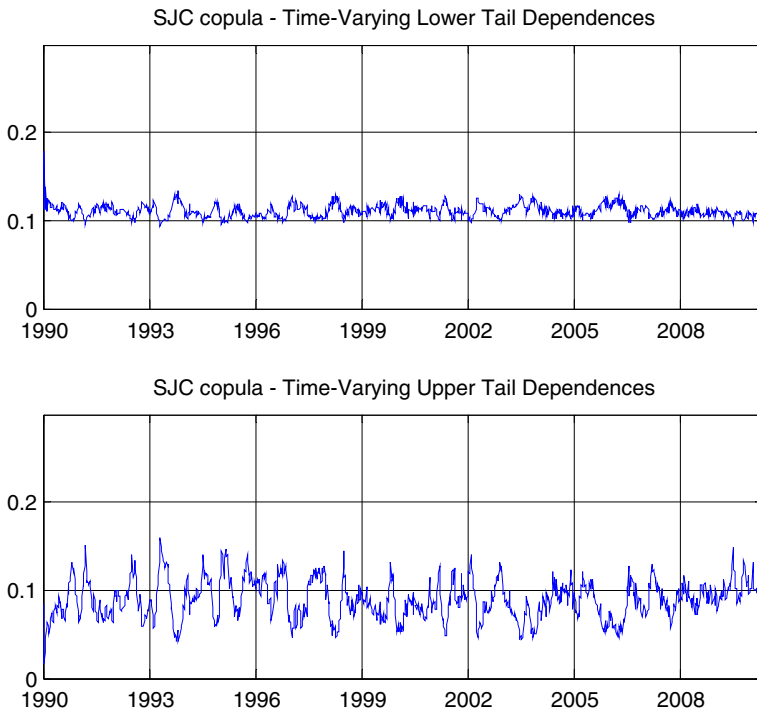


Fig. 16 Time-varying tail dependences with structural breaks—U.S. & Australia

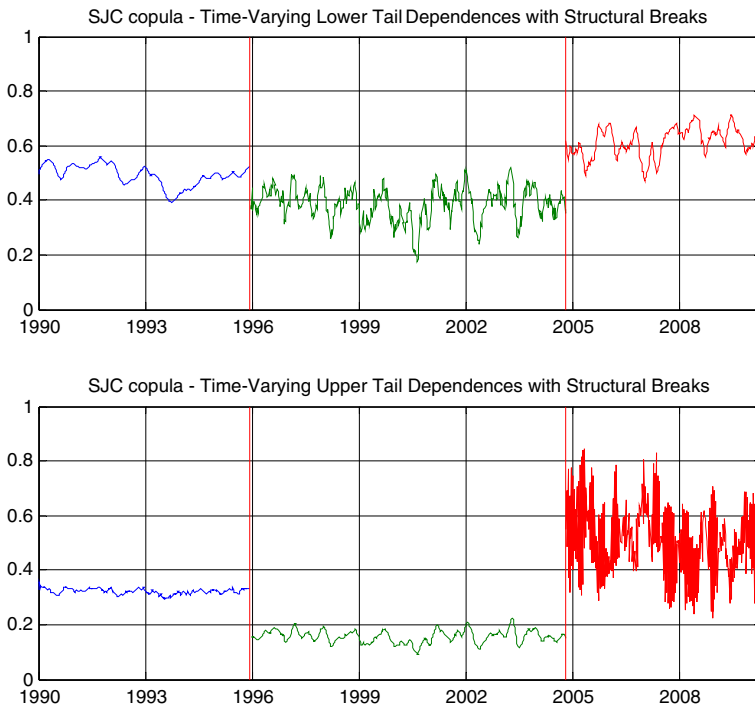


Fig. 17 Time-varying tail dependences with structural breaks—stocks & real estate stocks (U.S)

In summary, we observe a contagion phenomenon only between the U.S. and the U.K. real estate security markets occurring in 2007, the other pairs of markets showing either no structural break (the U.S. with Australia) or the presence of breaks which are not due to a crisis (the U.S. real estate stock market with the broader stock market). The implications are twofold. First, given that the relationships between assets/markets are not the same whether or not we consider the possibility of regime switching, it is likely that risk will be misestimated during some periods. Second, the economy of a country may be seriously affected by significant changes occurring in another economy as shown by the spreading of the recent financial crisis from the U.S. to the rest of the world.

Concluding Remarks

In this article, we investigate the relationships between local equity and securitized real estate markets, but also those existing between the world real estate security market and three local markets (i.e., those of the U.S., the U.K. and Australia). Three aspects of those relationships are considered to obtain a comprehensive view of the underlying features. First, the volatility spillover patterns are analyzed using an asymmetric t-BEKK model. Second, using an approach embedded in copula theory, we estimate both constant and time-varying tail dependences. More specifically, we have chosen the symmetrized Joe-Clayton copula proposed by Patton (2006)

because of its flexibility. Third, we test for financial contagion in the sense of Forbes and Rigobon (2002) and Bae et al. (2003). For doing so, we look at the presence of structural breaks in the previous copula parameters (i.e., in tail dependences) by employing the test of Dias and Embrechts (2004).

Our article yields the following main results:

1. The strongest volatility spillovers between the stock and the securitized real estate markets are found in the U.S.
2. The three national markets influence more the volatility of the global market than the reverse.
3. Rather important tail dependence coefficients are observed (in both domestic and international analyses).
4. A quite constant trend is found in the time-varying tail dependences over the 1990–2010 period (except for Australia in the domestic analysis), contrasting with the conditional correlations which show a clear upward trend since 2005.
5. Generally, currency movements do not contribute to our findings.
6. Evidence of financial contagion is only found between the U.S. and the U.K. markets and follows the subprime crisis.

Our analysis sheds light on the complexity of the dynamics underlying the securitized real estate markets and should prove useful in devising international real estate security portfolio strategies. Given that direct real estate and real estate securities exhibit rather strong linkages in the longer term and knowing that real estate and housing markets have a noticeable impact on the economy of a country (the recent subprime crisis is a clear illustration of this), the results of this paper should also be useful to policy makers.

Three avenues for future research should be fruitful. An extension of this paper would be to test for financial contagion by means of a structural break test which would take into account the time-varying feature of the tail dependences. Further, a more detailed analysis of the shock transmission mechanisms underlying the financial contagion would expand this line of research. Also, consideration should be given to the implications of our results for return predictability and market efficiency.

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